Empirical Relationships of Elastic Modules and Uniaxial Strength of Intact Metamorphic Rocks of Sri Lanka

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ABSTRACT: The strength characteristics of intact metamorphic rocks were determined for 175 samples of metamorphic rocks of Sri Lanka named as Charnockitic gneiss (CHG), Garnet-biotite gneiss (GBG) and Marble (MBL)including measurements of stress-axial strain, stress-lateral strain, Young's modulus, E, Poisson's, μ and Modules Ratio, M_R. Empirical relations between E, σ_i, $€_a$, M_R for above rocks were assessed. It is clear that the average elastic modulus is partly related to uniaxial compressive strength with small $R^2 = 0.182$ to 0.418 in both CHG and GBG samples and MBL does not influence the M_R value (R^2=0.082 is very small). The investigation on correlation between maximum axial strain and Modulus ratio revealed that the relationship if strong: $R^2 = 0.759$.

1 INTRODUCTION

1.1 *Introduction*

The deformation and intact strength properties of metamorphic rock cores are fairly important in design of rock slopes, underground tunnels, deep caverns and blasting designs etc. Depending on the mode of the acting geological force and type of geological media, three types of deformation can result as well as three elastic moduli that correspond to each type of deformation. Young's modulus, E, is the ratio of uniaxial compressive σ_i (tensile) stress to the resultant strain. Bulk modulus, K, is the change in volume under hydrostatic pressure (i.e., the ratio of stress to strain and K is the reciprocal of compressibility). Shear modulus, G, is the ratio of shearing (torsional) stress to shearing strain. Poisson's ratio, μ, is a measure of the geometric change of shape under uniaxial stress. The average elastic modulus is determined as the slope of the linear portion of stress–strain curve. It is well known that the elastic modulus increases with increasing uniaxial compressive strength; and there are different empirical relationships between σ_i and E obtained for many metamorphic rocks (Palchik 1999; Palchik 2006; Ocak 2008).

1.2 *Geology of Sri Lanka*

The metamorphic basement of Sri Lanka has been considered as a key terrain to understand the evolution of Gondwana supercontinent (Sanjeewa, P. K .Malaviarachchi et al.; 2011). Precambrian rocks which metamorphose under granulite facies and amphibolite facies are sub divided in to three groups on the basis of lithology, structures and age of the rocks. They are Highland complex (HC), Vijayan complex (VC) and Wanni complex (WC) with the Kadugannawa complex as a subordinate unit (Cooray, 1984). The Highland complex rocks comprises mainly of granulite grade charnockitic rocks, and meta-sediments. The Highland complex is bounded on the east by the amphibolite grade Vijayan complex. The Wanni complex consists mainly of Granitic gneisses, Charnockitic gneisses, and migmatites, and the metamorphic grade ranges from amphibolite to granulite (Mathavan et al., 1999). Crystalline Limestone (Marble) is categorized under the Highland complex rocks.

2 METHODOLOGY AND LIMITS

Determination of strength characteristics of metamorphic rock samples collected from the central province of Sri Lanka are mainly based with ASTM standard D 7012-4. Test specimens were subjected to uniaxial compression to find out compression strength, stress-axial strain, $€_a$ and stress-lateral strain $€_l$, Young's modulus, E and Poisson's ratio, μ of rock cores. It should be noted that test method makes no provision for pore water pressure measurements. Tensile stresses and strains are normally recorded as positive. Axial strain $€_a$ and lateral strain $€_l$ were measured through wire strain gauges recoded from the fully automated digital readout unit and plotting of results is as shown in the Fig 1. The complete curve gives the best description of deformation behavior of rocks having nonlinear stress-strain relationship at low and high stress levels.

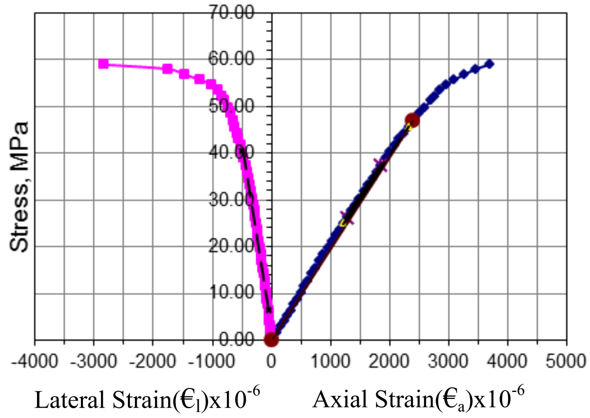

Fig. 1 Stress-versus-stain curve for axial and lateral direction in tested sample.

However, mathematically analyzing the observed stress–strain relations for weak-to-strong (5 MPa\ σ_i\100 MPa) rock samples, Palchik (2006) has created a stress–strain model based on Haldane's distribution function, which relates the axial stress to the square of an exponential function, where the exponent is axial strain ($€_a$). Therefore, study extended to determine the values of modules ratio, $M_R = E_{av}/ \sigma_i$ for all selected samples to define how uniaxial compressive strength and maximum axial strain (at a uniaxial compressive strength) influence these M_R values. In addition, the findings were also focused to define shear modules and the bulk modules considering an isotropic material.

3 LABORATORY PARAMETERS OF ROCKS

Samples were selected considering in-situ variations of weathering conditions by macroscopic analysis of intact rocks according to the BS 5930:1999 of Charnockitic gneiss (CHG), Garnet-biotite gneiss (GBG) and crystalline limestone or Marble (MBL). The findings of uniaxial compressive strength of selected rock samples are shown in the Fig.2 to Fig.4. Sample count representing notations of FR-fresh rock and MWR-moderately weathered rock respectively.

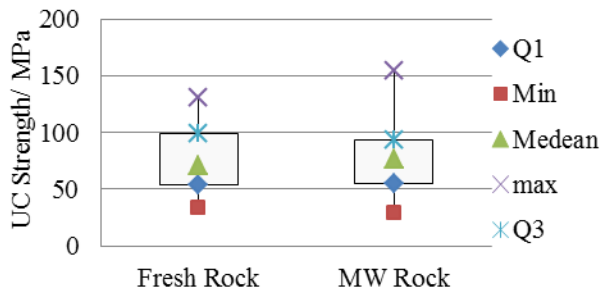

Fig. 2 Uniaxial Compressive Strength variation of Garnet-biotite gneiss rock (FR-51 and MWR-22) samples.

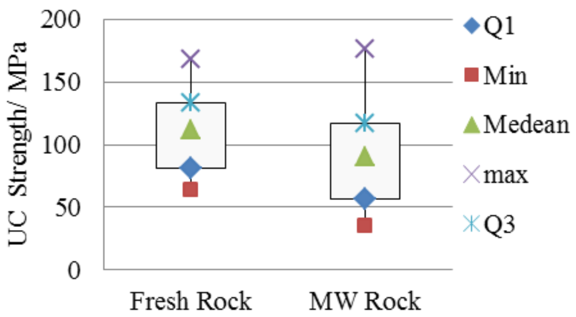

Fig. 3 Uniaxial Compressive Strength variations of Charnockitic gneiss/charnockitic rocks (FR-35 and MWR-31) samples.

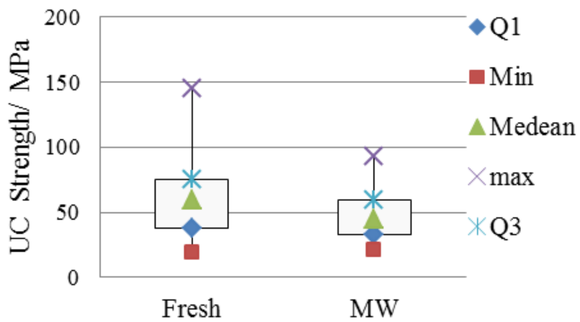

Fig. 4 Uniaxial Compressive Strength variation of crystalline Limestone/Marble (FR-15 and MWR-21) samples.

175 uniaxial compressive tests were conducted on selected metamorphic rock samples of Charnockitic gneiss (35.4 MPa\ σ_i\176.2 MPa), Garnet- biotite gneiss (33.1 MPa\$\sigma_i$ \154.7 MPa) and Marble (19.2 MPa\$\sigma_i$ \145.0 MPa) exhibiting wide ranges of average elastic modulus, E_{av} (E_{av} = 3.8–70.7 MPa), Poisson's ratio (μ = 0.10–0.40), and dry bulk density (ρ = 2.32–3.40 g/cm^3) as shown in the Table 1 below. The observed range of M_R = 74–1291 is noticed for metamorphic rock samples.

Table 1. Summary of Results (samples of Charnockitic gneiss (CHG), Garnet- biotite gneiss (GBG) and Crystalline Limestone (MBL).

Rock Type	Weathering condition	Density/ (g/cm^3)	Young's Modulus		Poisson's Ratio (μ)	(σ_i) / MPa	M_R (Modules Ratio)	Bulk Modulus (K)/ GPa	Shear Modulus (G)/ GPa
			Average Modulus (E_{av})/ GPa	Secant Modulus (E_{70})/ GPa					
CHG	FR	2.32-3.07	18.4-70.7	14.6-49.5	0.14-0.39	63.7-167.7	175-972	7.36-25.43	10.59-107.12
	MWR	2.42-3.30	7.5-57.9	8.6-59.6	0.14-0.4	35.4-176.2	116-643	3.1- 20.68	4.07-96.5
GBG	FR	2.59-3.30	11.3-48.8	11.1-52.7	0.11-0.34	33.1-131.0	126-1081	5.04-19.37	4.96-33.89
	MWR	2.50-3.40	8.5-62.8	6.9-40.5	0.13-0.33	29.2-154.7	74-1291	3.37-26.84	5.9-31.72
MBL	FR	2.57-3.01	3.8-35.7	10.0-35.1	0.11-0.30	19.2-145.0	149-782	1.64-14.28	1.86-24.44
	MWR	2.63-3.02	4.0-35.7	4.0-36.2	0.10-0.37	20.6-93.39	81-741	1.82-14.40	1.67-27.18

Secant Modulus of Sri Lankan metamorphic rocks Chanockitic gneiss and Biotite gneiss has been determined. The mean value and standard deviation of Charnockitic gneiss are 139 GPa and 92 GPa respectively and that of Biotite gneiss are 64 GPa and 38 GPa. (Jayawardena, 2009)

4 INTERPRETATION OF RESULTS

Detail empirical correlations were made by plotting of results between uniaxial compressive strength (σ_i) on elastic modulus (E_{av}) and the value of M_R. The complete curve gives the best description of deformation behavior of rocks having non-linear stress-strain relationship at low and high stress levels. The complexities of such representations are shown in the Fig 5 to Fig 7 for all 175 samples.

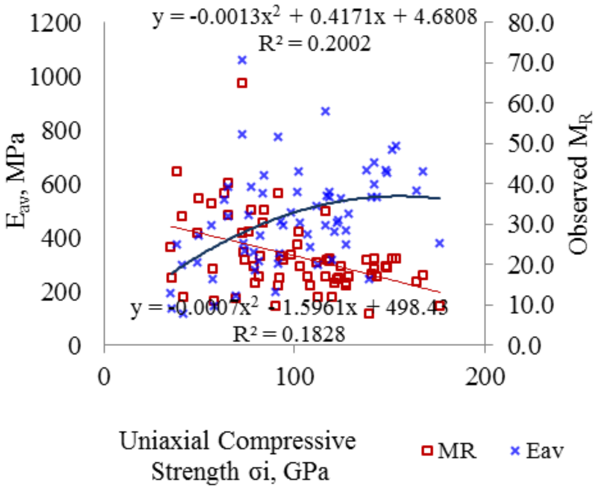

Fig .5 Influence of uniaxial compressive strength (σ_i) on elastic modulus (E_{av}) and the value of M_R for Charnockitic gneiss (CHG) rock samples.

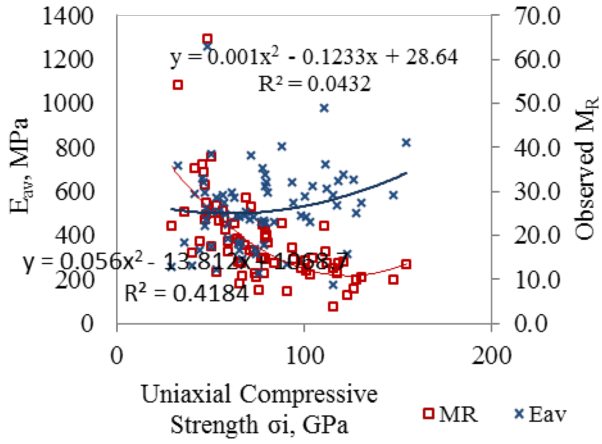

Fig .6 Influence of σ_i on E_{av} and the value of M_R for Garnet- biotite gneiss (GBG) samples

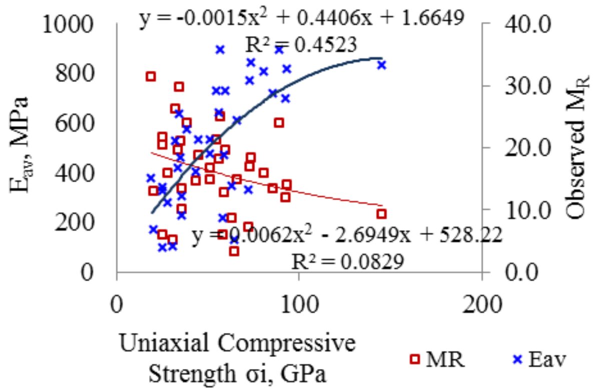

Fig . 7 Influence of σ_i on E_{av} and the value of M_R for crystalline Limestone/Marble(MBL)samples

It is clear that the M_R is partly related to uniaxial compressive strength with small $R^2 = 0.182$ to 0.418 in both CHG and GBG samples and MBL does not influence the M_R value (R^2=0.082 is very small). That means all interpretations have different empirical coefficients and different degrees of reliability (0.082\R^2\0.418).

The study was finalized $M_R = E_{av} / \sigma_i$ for three different metamorphic rocks (CHG, GBG & MBL) exhibiting a wide range of uniaxial compressive strength 19.2\ σ_i \176.2 MPa) and elastic modulus (E_{av} = 3,800–70,700 MPa), and also defined how uniaxial compressive strength, maximum axial strain (at a uniaxial compressive strength) influence these M_R values.

Elastic modulus (E_{av}) and prediction model were formulated using axial stress coordinates expressed in terms of uniaxial compressive strength (σ_i) and exponential function of axial strain according to the stress–strain model based on Haldane's distribution function (Palchik , 2006). Therefore, influence of maximum axial strain on Modules ratio M_R was studied for all test samples except few ambiguity data. The relationship was remarkably representing high R^2=0.759 and value of M_R for all fresh to moderately weathered rocks of metamorphic rocks is as in the Fig 8 below.

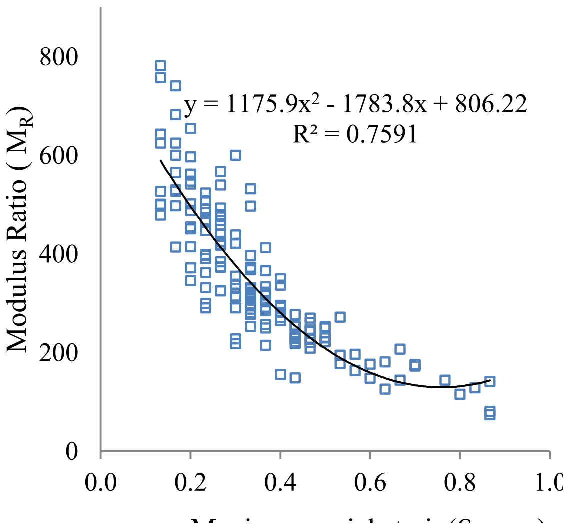

Fig .8 Most preferred relationship of maximum axial strain and the modules ratio (M_R) with all rock samples.

However, the strength of rock cores measured in the laboratory usually does not accurately reflect the large scale in-situ properties because the latter are strongly influenced by joints, fractures, lineaments, in-homogeneities, weakened planes, etc. Therefore, in most instances laboratory values are subjected to various comments and issues of acceptability when comparing with the mass rock behavior.

5 CONCLUSIONS

The study confirms that there are no reasonable empirical correlations between uniaxial compressive strength (σ_i) on elastic modulus (E_{av}) and the value of M_R of intact metamorphic rocks in Sri Lanka (CHG, GBG and MBL). It is also observed that the parameter M_R is inversely related to the maximum axial strain (€$_a$ max). The ratio between E_{av} and σ_i is a polynomial function of the maximum axial strain not only in gneiss rocks, but also in crystalline limestone rock samples.

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